CHAPTER 1

INTRODUCTION

1.1 General Description of the Present DØ Detector

The DØ detector is one of two major hadron collider detectors at the Fermilab Tevatron. DØ was originally proposed [1] and officially approved in 1984 and completed early in 1992 [2] and began taking data from proton-antiproton collisions at 1.8 TeV shortly thereafter. The DØ detector was designed and constructed to be a non-magnetic general purpose detector for high $p_\perp$ physics, aimed at searching for new high mass particles including the top quark, as well as studying heavy quarks, W and Z particles, and jets.

A perspective view of the present DØ detector, located in the DØ straight section of the Tevatron collider, is shown in Figure 1.1. The detector has three major distinct components: a central tracking detector system, a uranium liquid argon calorimeter system, and a muon detector system.

The calorimeter system consists of three calorimeters, a central calorimeter CC, and two end calorimeters, EC's [3]. The present central tracking detectors are mounted inside the central opening of CC, as shown in Figure 1.1.

The muon detector consists of a set of toroidal magnets and a proportional drift tube (PDT) system [4]. The PDT's are arranged in planar arrays with one layer inside the steel yokes of the toroid magnet and two layers outside the toroid yokes. The toroids for the wide angle muon system (WAMUS) consist of three principal magnetized steel toroids: the central toroid CF, and two end toroids, EF's. The coils of the three WAMUS magnet systems are connected in series and operate at 2500 amperes at either polarity. A small angle muon system (SAMUS) consisting of similar arrays of PDT's and smaller magnetized steel toroids is fitted closely in the aperture of each EF. The two SAMUS toroids are operated in series at 1000 amperes.

To permit access to the interior of the detector the CF toroid is composed of three sections: a fixed central base beam and two moving side yokes. The central base beam is supported on a platform which supports the entire detector and it in turn supports the calorimeters and central tracking systems. The two CF side yokes move laterally on the platform to allow access to the detector components interior to the CF system. The two EF toroids move longitudinally on the platform, so that when they are moved apart the two EC vessels can also be moved back along the central base beam to permit access to the CC and the tracking system mounted within it.

The platform on which the entire 5000 ton detector is mounted moves into and out of the DØ collision hall. Full electrical, cryogenic, and electronic services are maintained in both the assembly and collision halls and the entire detector can be operated in either area. Great care has been taken to provide electrical noise isolation for all elements of the detector on the platform so that spurious signals are not captured by the sensitive detector electronics on the platform and sent to the data acquisition system.

1.2 Upgrade Project of the DØ Detector

Well before the DØ detector began its first data taking run in early 1992 the luminosity of the Tevatron was scheduled to increase in an evolutionary way over the course of several years [5], involving as well a decrease in the bunch crossing time from the present 3.5 μsec to eventually less than 400 nsec. Thus an upgrade project for the DØ detector was proposed [6] which explored the ways to prepare the detector for the increased capabilities of the Tevatron which will ultimately deliver luminosity nearly two orders of magnitude greater than that available when the DØ detector was first commissioned.

The final configuration of the upgraded detector has been driven by the need to accommodate the change in accelerator conditions, the availability of new detector-technology options, and the exploitation of the new physics capabilities, including heavy quark physics at lower $p_\perp$, which the Tevatron will facilitate. The increasing radiation dosages delivered to the existing central tracking system of the detector will soon begin to degrade its performance; the replacement of this system with a new radiation-hard high-precision magnetic tracking system with excellent electron identification is a key element in the DØ upgrade.

This report details the design of a thin 2 Tesla superconducting solenoid magnet to be installed in the aperture of CC. The arrangement of the new central tracking system including the solenoid magnet is shown in Figure 1.2. Particles outgoing from the interaction point first encounter the thin beryllium beam vacuum tube of the Tevatron, then a set of precision silicon microstrip vertex detectors, a four layer scintillating fiber tracking system, the thin solenoid magnet, and an electron preshower detector. The preshower detector just outside the magnet cryostat will aid in electron identification and will compensate the response of the electromagnetic calorimetry for the effects of unavoidable materials in the solenoid and inner tracking systems.

The tracking systems in the bore of the solenoid will be supported by the magnet cryostat vacuum vessel, and the preshower detector just outside the solenoid will likewise be supported by the magnet cryostat, which in turn is supported by the CC vacuum vessel. A perspective view of the solenoid inside the CC (omitting one EC and EF for clarity), together with its chimney and control dewar, is shown in Figure 1.3.

1.3 General Requirements for the Superconducting Solenoid

The overall physical size of the thin 2 Tesla solenoid is determined by the dimensions of the existing aperture of the CC vacuum vessel. The overall dimensions of the proposed solenoid are 2.73 meters in length and 1.42 meters in diameter.

The central field of 2 Tesla is selected considering the optimization of momentum resolution $\Delta p\_/p\_$ and tracking pattern recognition, the overall available space in the CC aperture, and the necessary thickness for the cryostat which depends on considerations of the thickness of the conductor and support cylinder.

Because the muon toroids are located several meters from the solenoid magnet and symmetrically placed outside it, there will be modest magnetic interaction between the steel of the muon system and the solenoid. Much of the magnetic flux generated by the solenoid returns in the space between the cryostat and the muon system. This volume is nearly entirely filled with the uranium argon calorimeters and associated electronics, a scintillator-based intercryostat detector (ICD) system, and the first layer of the muon proportional drift tubes (PDT's). The Main Ring beam pipe also traverses this space, penetrating the calorimeter vessels themselves.

The effects of this field on the muon PDT's, where it and the fringe fields from the existing muon toroid coils reaches 500 Gauss have been studied and have been shown to be unimportant. The same is true of the calorimeter. The photomultiplier tubes of the ICD will require replacement or relocation and the Main Ring will require specific attention if it has not been replaced by the Main Injector [5] prior to the installation of the solenoid. The field at the Main Ring beam pipe reaches 300 Gauss and it has been found that a thick iron shielding pipe will be sufficient to protect the Main Ring beam from harmful perturbations due to the solenoid fringe field if the Main Injector is delayed.

The major requirements for the proposed solenoid are as follows:

1. 2 Tesla Central Field:

   With the present technology and materials for thin coil superconducting solenoids, it is possible to design a solenoidal magnet with a 2 Tesla central field which will operate stably and safely at all times.

2. Uniformity of Magnetic Field:

   The inside volume of the solenoid which is occupied by the tracking system should have uniform field over as large a percentage of the volume as practical to optimize the pattern recognition and the momentum resolution of charged particles.

3. Geometrical size:

   The solenoid, together with the preshower detector, must fit in the existing inner clear bore of the DO Central Calorimeter. To make the tracking space as large as possible the cryostat should be made as thin as practical.

4. Thinness in Radiation and Interaction Length:

   To preserve the present electromagnetic energy resolution of the existing DØ calorimeter the materials for the solenoid should be chosen to reduce their radiation and interaction length as much as practical. The effective radiation length of the solenoid materials will be utilized as a part of the electron converter, together with a lead sheet wrapped around the outer surface of the cryostat with thickness graded so that the total combined thickness is nearly independent of scattering angle.

5. Chimney:
   A service chimney carrying cryogens, magnet high current buses, and vacuum pump-out and relief, must reach the magnet through the narrow space between the CC and EC vacuum vessels. The narrowest space between these calorimeters is 7.6 cm wide, and the chimney must be designed to fit this space.

6. Control Dewar:
   The control dewar for the solenoid will be mounted on the DØ detector cryobridge structure as shown in Figure 1.3. A turbo pump for the magnet vacuum system will also be supported by the cryobridge.

7. Remote Operation:
   The entire detector system operates in the DØ collision hall which is a radiation environment when the Tevatron and Main Ring are operating. There is no personnel access to this hall at this time. The magnet system must permit full remote operation, including cool down, energization, de-energization for field reversal, quench recovery, and warmup, without operator access to the magnet cryostat, service chimney or control dewar.

The major parameters of the DØ Solenoid design are shown in Table 1.1. The parameters of the proposed solenoid are compared with those of the ZEUS [7] detector solenoid at DESY and the CDF[8] solenoid at the Tevatron in Table 1.2. The ZEUS solenoid was designed with a central field of 1.8 Tesla with similar field homogeneity requirements, but placed asymmetrically relative to the steel structure of the ZEUS detector. The stored energy of the proposed DØ solenoid is approximately 5.6 MJ. This stored energy is much smaller than the 30 MJ of CDF or the 12.8 MJ of ZEUS, and the stored energy per unit cold mass of the DØ coil has been made lower than either of these magnets as well. Because design choices for the DØ solenoid can be made which are fundamentally conservative, the proposed solenoid while technically advanced does not surpass state-of-the art and will lend itself to ready fabrication.

References

[1] Design Report, "The DØ Experiment at the Fermilab Antiproton-Proton Collider", November, 1984.

[2] S. Abachi, *et al.*, "The DØ Detector", Nuclear Instruments and Methods in Physics Research, **A338**, 185, 1994.

[3] S. Abachi, *et al.*, "Beam Tests of the DØ Uranium Liquid Argon End Calorimeters", Nuclear Instruments and Methods in Physics Research, **A324**, 53, 1993.

[4] C. Brown, *et al.*, "DØ Muon System with Proportional Drift Tube Chambers", Nuclear Instruments and Methods in Physics Research, **A279**, 331, 1989.

[5] G. Dugan, Accelerator Upgrade and the Main Injector, DØ Note 976, June 12, 1990.

[6] DØ Upgrade, DØ UPG-01, 10/18/1990; also P823, (DØ Upgrade), DØ Note 1148, June 18, 1991; also E823, (DØ Upgrade), DØ Note 1426, May 20, 1992.

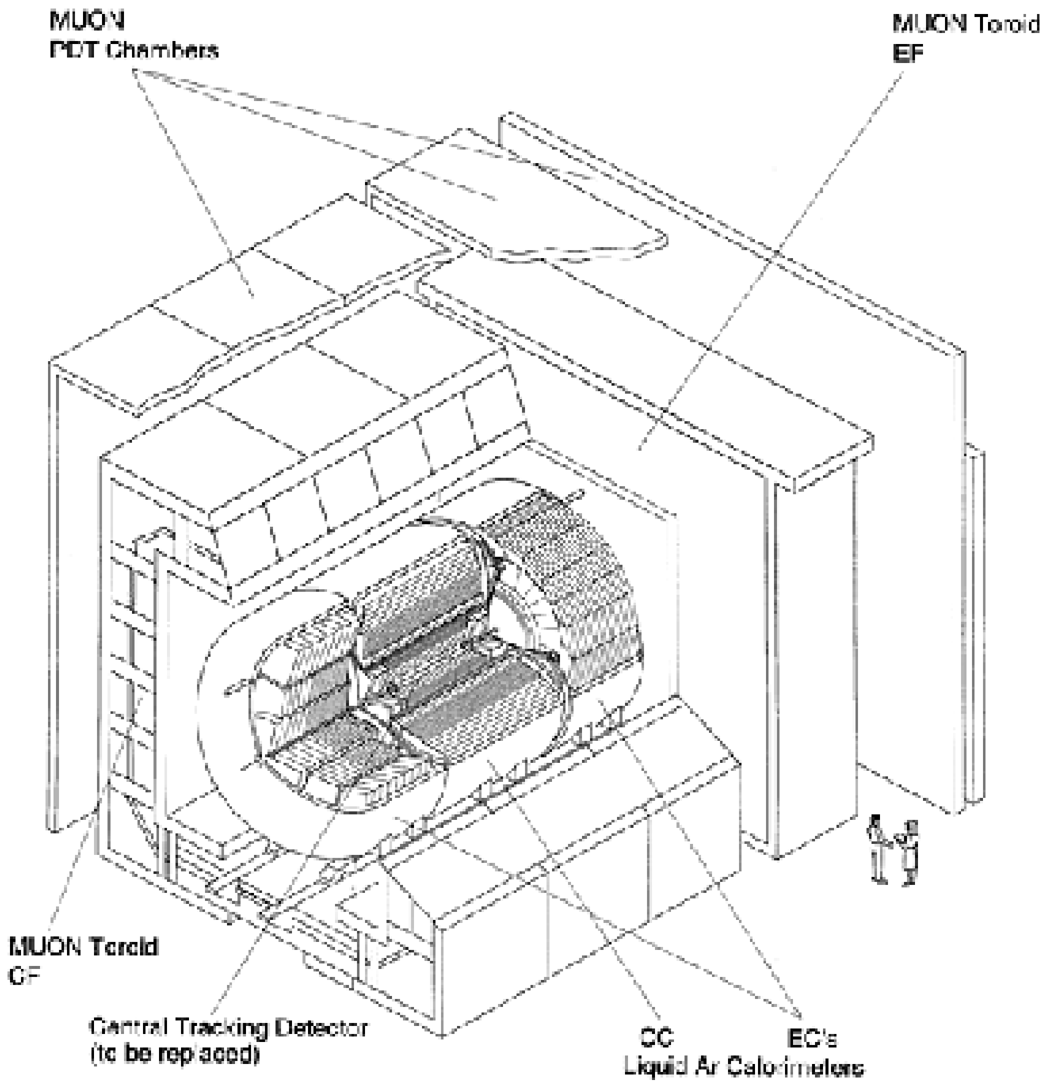
[7] A. B. Olivia, *et al.*, "ZEUS Magnets Construction Status Report", Proceedings of the 11^{th} International Conference on Magnet Technology, 229, 1989.

[8] R. W. Fast, *et al.*, "Testing of the Superconducting Solenoid for the Fermilab Collider Detector", Advances in Cryogenic Engineering **V31**, 181, 1986, Plenum, NY.

TABLE 1.1: DØ Solenoid Parameter Summary	
Parameter	Selected Value
Central Field	2 T
Operating Current	4825 A
Charging Time	7 min
Stored Energy	5.6 MJ
Inductance	0.48 H
Protection Resistor	0.048 Ohm
Cryostat Dimensions:	
Length	273 cm
OD	141.6 cm
ID	106.6 cm
Material:	
Coil Support Cylinder	Aluminum 5083-0
Cryostat	Aluminum 5083-0
Vacuum Vessel Design	Designed for full vacuum and 6.4 psi internal pressure
Control Dewar Design	Designed to ASME code
Cold Mass Supports:	
Shipping	Designed for 4g radial
	Designed for 6g axial with shipping restraints
At 4.7 K	Designed for 2g radial
	Designed for 1g axial
Superconductor:	High-purity aluminum stabilized multi-filamentary Cu-NbTi Rutherford cable
Conductor Grade I	5.125 x 15 mm
Conductor Grade II	3.820 x 15 mm
Cryogenics:	
Temperature of Cold Mass	
maximum	4.9 K
nominal	4.7 K
Coil Cooling Technique	Indirect, with 2 phase LHe forced flow
Radiation Shield Cooling	LN2 forced flow
Refrigeration System	Shared Fermilab 600 W Satellite Refrigerator

TABLE 1.2: Comparison of Thin Solenoids				
Parameter	**Units**	**DØ**	**ZEUS**	**CDF**
Central Field	T	2.0	1.8	1.5
Stored Energy	MJ	5.6	12.5	30
Radiation Thickness	A	0.87	0.9	0.83
Inductance	H	0.48	1.28	2.4
Total Weight	kG	2300		11100
Cold Mass	kG	1460	2000	5570
Cryostat Outside Radius	cm	70.7	111	167.7
Cryostat Inside Radius	cm	53.3	86	142.9
Cryostat Length	cm	273	285	507
Coil Winding:				
Support Cylinder Thickness	mm	15	18	16
No. of Layers		2	2	1
Inner Radius	cm	58.7	92.5	148.3
Length	cm	256.6	248.7	479.4
No. of Turns		1010	907	1150
Total Amp-Turns	10^6	4.87	4.54	5.75
Conductor:				
Conductor Grade I	mm x mm	5.125 x 15	5.56 x 15	
Conductor Grade II	mm x mm	3.830 x 15	4.3 x 15	3.89 x 20
Conductor Radial Width	mm	15	15	20
Turn to Turn Ins	mm	0.5	0.5	0.1
Al:Cu:NbTi I	Parts	19.3:1.3:1	18:1.1:1	21:1:1
Al:Cu:NbTi II	Parts	13.8:1.3:1	14:1.1:1	
Stabilizer Al	Purity	99.996	99.996	99.99
Superconductor:				
Form		Cable	Cable	Monolith
Dimensions	mm^2	8.20 eff	8.4 eff	6.93
Operating Current	A	4825	5000	5000
Short Sample Current	A	14400	15000	10400
@ (B_{peak}, T_{op})	(T, K)	(2.3, 4.7)	(2.3, 4.5)	(1.5, 4.4)
I_{op}/I_c (load line)	%	55	54	60

TABLE 1.2 (cont): Comparison of Thin Solenoids				
Parameter	**Units**	**DØ**	**ZEUS**	**CDF**
Details of Cryostat:				
Total Radial Thickness	mm	174.5	250	248
Vacuum Shell Aluminum		5083-0	6063-T6	5083-0
Outer Vacuum Shell Thickness	mm	8	12	19
Outer Radiation Shield Thickness	mm	1.6	3.0	2.0
LHe Cooling Pipe	mm ID	15	18	16
Conductor+Insulation	mm	35.4	32	23.5
Inner Radiation Shield Thickness	mm	1.6	3.0	2.0
Inner Vacuum Shell Thickness	mm	6.4	5.0	6.4
Axial distance between				
Cryostat & Coil	mm	53.0	182	137
Bulkhead Thickness	mm	20	30	25.4
Decentering Force:				
Axial	10^4N/m	6.9	(.5 Tons)	1760
Radial	10^4N/m	1.1	2	1230



DØ Detector

Figure 1.1

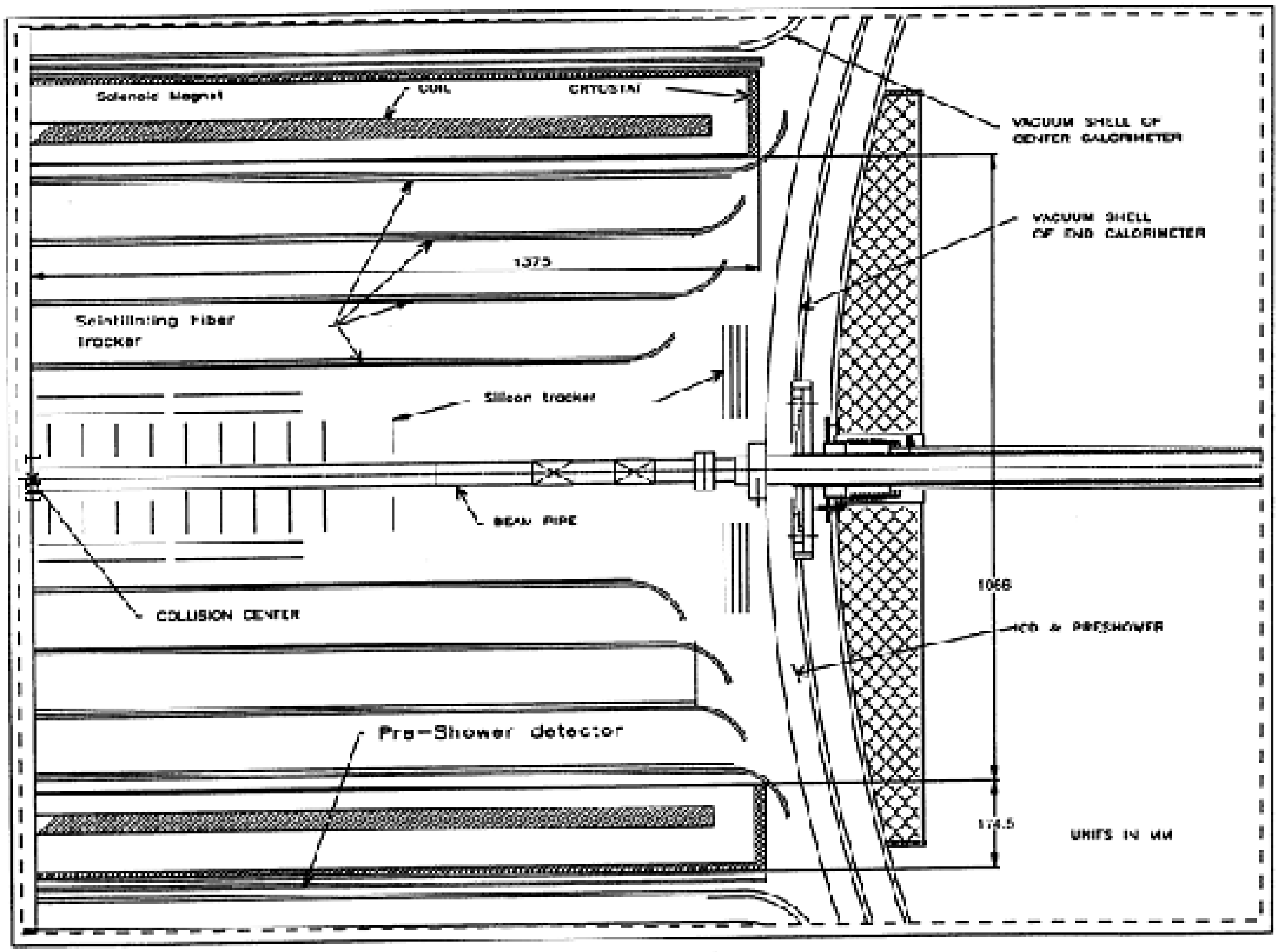
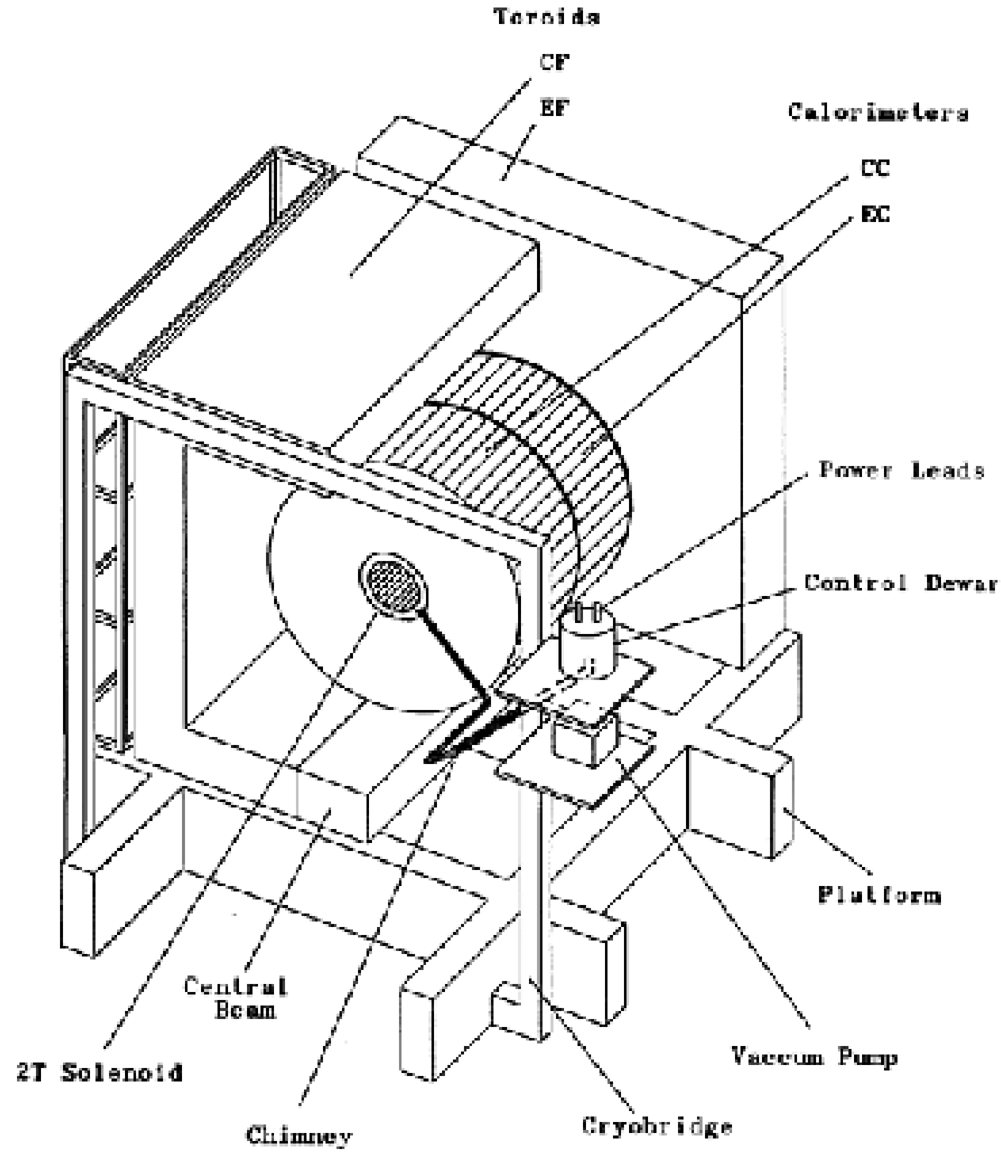

Solenoid Magnet
COIL
CRYOSTAT
VACUUM SHELL OF
CENTER CALORIMETER
VACUUM SHELL
OF END CALORIMETER
1375
Scintillating Fiber
tracker
Silicon tracker
BEAM PIPE
COLLISION CENTER
1068
PRESHOWER
Pre-Shower detector
174.5
UNITS IN MM

FIGURE 1.2



Toroids
CF
EF
Calorimeters
CC
EC
Power Leads
Control Dewar
Platform
Vaccum Pump
Cryobridge
Chimney
2T Solenoid
Central
Beam

FIGURE 1.3